Predictability of stratospheric circulations during recent sudden warming events

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1. Introduction

Recently, the predictability of stratospheric sudden warming (SSW) events has attracted much attention by upsurging interests on such stratospheric-troposphere dynamical coupling (e.g., Christiansen 2003, Reichler et al. 2005).

Mukougawa and Hirooka (2004) examined the predictability of SSW occurring in December 1998 using the operational ensemble 1 month forecast data produced by the Japan Meteorological Agency (JMA). They mentioned that the root-mean-square error (RMSE) in the stratosphere tends to be larger during SSWs and the enhancement is mainly caused by the poor prediction of the phase of planetary waves. Moreover, they indicated the possibility that the SSW is predictable more than 1 month in advance.

Mukougawa et al. (2005) examined a predictable period of the warming peak occurring in December 2001 in terms of 10 hPa zonal mean temperature at 80N using same datasets. They reported that the warming is predictable at least from 2 weeks in advance. However, that of SSWs occurring in January 2004 and January 2006 are at most 10 days (Hirooka et al. 2007, etc). The predictability depends on the occurrence pattern of each SSW.

In this study, we investigate the predictability of stratospheric circulations during mainly sudden warming events in recent five Northern Hemisphere winters (2001-2006) using the JMA ensemble 1 month forecast data. Each limitation of predictability (hereafter LP) is estimated on the basis of the growth of root-mean-square errors (RMSE) and that of the pattern correlation in 10-hPa geopotential height. Additionally, we examine predictable periods of various warming peaks in terms of the averaged zonal mean temperature north of 80N at 10 hPa and compare its result with the LP evaluated by RMSE and the pattern correlation.

2. Model and Data

(1) 1-month forecast data of JMA ensemble prediction system

Resolution	T106 L40 hybrid coordinate
Top Boundary	0.4 hPa
Integration Period	34 days
Number of Ensemble	13 members
Perturbation Method	BGM (Breeding of Growing Mode)
Initialization Date	Every Wednesday and Thursday
Interval of Stored Data	Daily (2.5 ° x 2.5 °)

(2) JMA operational stratospheric assimilated data
(Resolution) 1.25° x 1.25° Lon-Lat grid spacing
Vertical: 23 Pressure levels (1000 hPa - 0.4 hPa)

BGM method
Perturbations are created in quest of the large mode of the error growth which can serve as a perturbed ingredient from the past air field. If an air field hardly change, these perturbations are in agreement with the most unstable mode.

3. Methods

* The RMSE is defined by the following equation
(The summation is taken over 20N-90N)

$$RMSE = \sqrt{\sum_{i=1}^{N}\left(Z_f^i - Z_g^i\right)^2 / N}$$

* Climatological Standard Deviation (CSD) ;
the measure of the LP

$$\sqrt{\frac{1}{day}\sum_{j=1}^{day}\left(\sum_{i=1}^{N}\left(Z_g^i - Z_c^i\right)^2 / N\right)_j} = 232\,m \quad (at\ 10\,hPa)$$

* The pattern correlation is defined by the following equation ;
the time when this first reaches 0.6 is the LP.

$$Pattern\ Correlation = \frac{\sum (Z_f - Z_c)(Z_g - Z_c)}{\sqrt{\sum (Z_f - Z_c)^2 \sum (Z_g - Z_c)^2}}$$

10 hPa geopotential height
Z_g : Obs.
Z_f : Ensemble mean
Z_c : Climatology
* Applying a low-pass filter to 10 hPa geopotential height. The cutoff period is 90-day.

* RMSE indicates a forecast error, and RMSE score of zero (0.0) demonstrates perfect skill.
* Pattern Correlation indicates a patterns correlation between forecast anomaly and analysis anomaly.

* A SSW here is determined by conditions for the zonal-mean field at 10 hPa ;
It satisfies (A) or (B) with warming, and (C).
(A) the zonal-mean zonal wind at 60N is easterly
(B) the warming magnitude for 3 days is more than 15 K
(C) the warming peak interval is more than 10 days

4. Results

<4.1 Features of ensemble forecasts ; time variations of forecast errors>

Planetary Waves <inactive> Planetary Waves <active>

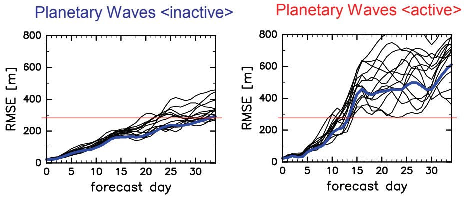


Fig.1 ; Examples of time variations of the RMSE when planetary waves are active and inactive.

inactive : forecast errors SMALL, spread SMALL → forecast skill GOOD
active : forecast errors LARGE, spread LARGE → forecast skill BAD

<4.2 Comparison of Average RMSE over 10-20 forecast days in five winters>

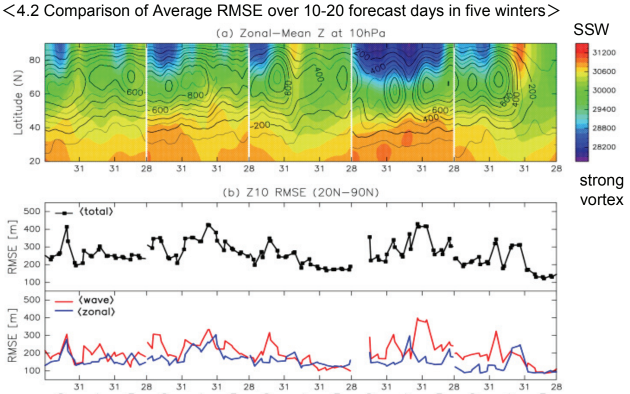


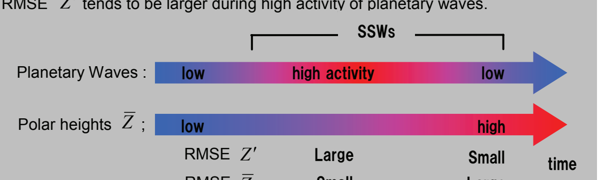
Fig.2 ; Time-latitude cross sections for (a) the 11-day averaged zonal-mean geopotential height (color) and the composed amplitude WN1-3 (contour) at 10 hPa. (b) Time variations of RMSE for the ensemble mean forecast averaged over 10-20 forecast days along with total (black), the wave (red) and the zonal-mean contributions (blue). Values between Thursday and Wednesday are linear-interpolated.

Decompose the RMSE into $\overline{Z}$ and Z'.

- Undisturbed periods (J,F 2004, F 2006) : Both RMSE $\overline{Z}$ and RMSE Z' are small and equally contributed to the total RMSE
- Amplified wave periods: RMSE $\overline{Z}$ and RMSE Z' become larger than those in undisturbed periods and frequently show anti-correlation relationship.

<The cause of anti-correlation relationship>

RMSE $\overline{Z}$ tends to be larger after high activity of planetary waves.
RMSE Z' tends to be larger during high activity of planetary waves.



<4.3 The limitation of predictability for stratospheric circulations ; RMSE and Pattern Correlation>

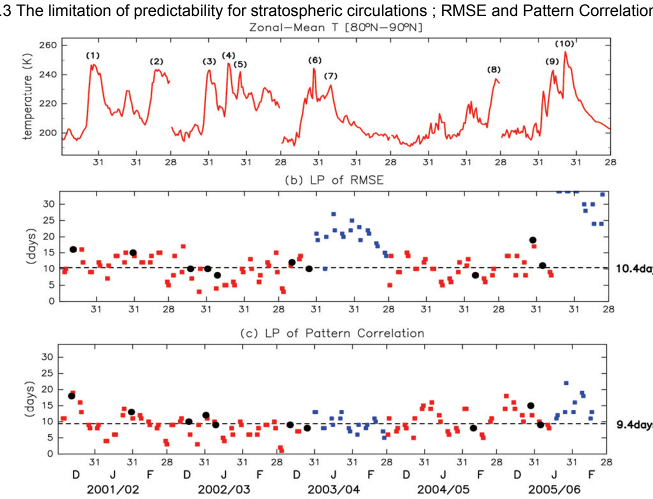


Fig.3 ; (a) Time variation of the averaged zonal mean temperature north of 80N at 10 hPa. SSWs are numbered. LPs are estimated on the basis of (b) the RMSE and (c) the pattern correlation. Red (blue) boxes are LPs during (un)disturbed periods. Dashed lines are an averaged LP during disturbed periods. Black circles denote LPs of the forecast performed before about two weeks of the warming peak.

<4.4 Predictable periods based on warming peaks>

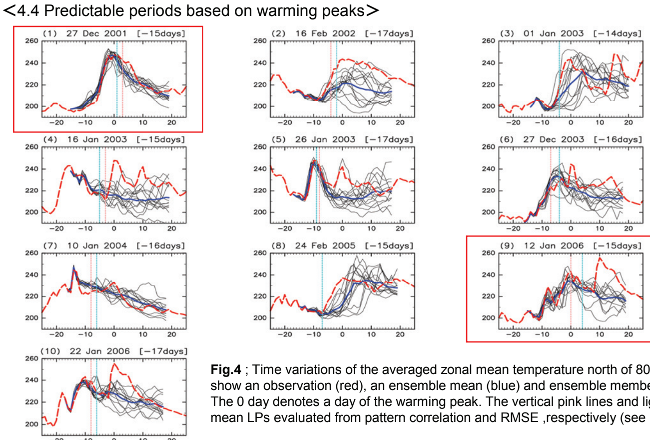


Fig.4 ; Time variations of the averaged zonal mean temperature north of 80N. Solid lines show an observation (red), an ensemble mean (blue) and ensemble members (black). The 0 day denotes a day of the warming peak. The vertical pink lines and light blue ones mean LPs evaluated from pattern correlation and RMSE ,respectively (see Fig.3).

5. Summary

In the stratosphere, not only RMSE Z' but also RMSE $\overline{Z}$ contribute to the total forecast error. During SSWs, they frequently show anti-correlation relationship. (see Fig.2)

During disturbed periods, the averaged LP is about 10 days. However, it is greatly different according to the case. In particular, SSWs occurring in Dec 2001 and Jan 2006 (Fig.4-1,4-9) are predictable at least from 2 weeks in advance. (see Fig.3)

LPs evaluated by RMSE and pattern correlation analyses are consistent with the predictable tendency of the zonal mean temperature. (see Fig.4)